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13. ABSTRACT *(Maximum 200 words)*

Recent technological advances allow symbology to be displayed on the pilot's visor. A major benefit of this is that the pilots will be able to take this information with them when they look off-boresight. However, when looking off-boresight, the question arises as to what is the best orientation, or frame of reference, for attitude symbology against the horizon (i.e., forward or line-of-sight) in order to maximize interpretation and performance. This study tested five different symbologies (standard HUD, visually coupled acquisition and targeting symbology, arc segmented attitude reference, theta ball, and non-distributed flight reference) of which three have both forward and line-of-sight orientations. The experiment consisted of two distributed tasks, with the pilots performing either facing the monitor or rotated 90 degrees and looking over their shoulder (off-boresight). In the first task, pilots maintained straight and level flight with simulated turbulence. The second task had pilots interpret a static representation of their attitude and respond via a key press, and then the display went live and they had to fly to a new commanded attitude. This second task was similar to a recovery from unusual attitude methodology, except the end state was never straight and level. Instead, a second unknown end-state attitude was commanded by the experiment. Results indicate that performance is letter when the symbology is forward as opposed to line-of-sight referenced. Further, performance was best in both tasks for the non-distributed flight reference. We discuss these results in terms of implications for helmet-mounted display symbology design.

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ABSTRACT

Recent technological advances allow symbology to be displayed on the pilot's visor. A major benefit of this is that the pilot will be able to take this information with them when they look off-boresight. However, when looking off-boresight the question arises as to what is the best orientation, or frame of reference, for attitude symbology against the horizon (i.e., forward or line-of-sight) in order to maximize interpretation and performance. This study tested five different symbologies (standard HUD, visually coupled acquisition and targeting symbology, arc segmented attitude reference, theta ball, and non-distributed flight reference) of which three have both forward and line-of-sight orientations. The experiment consisted of two different tasks, with the pilots performing either facing the monitor or rotated 90° and looking over their shoulder (off-boresight). In the first task, pilots maintained straight and level flight with simulated turbulence. The second task had pilots interpret a static representation of their attitude and respond via a key press, and then the display went live and they had to fly to a new commanded attitude. This second task was similar to a recovery from unusual attitude methodology, except the end state was never straight and level. Instead, a second unknown end state attitude was commanded by the experiment. Results indicate that performance is better when the symbology is forward as opposed to line-of-sight referenced. Further, performance was best in both tasks for the non-distributed flight reference. We discuss these results in terms of implications for helmet-mounted display symbology design.

Keywords: helmet-mounted display, symbology, attitude, flight reference, off-boresight.

1. INTRODUCTION

A primary benefit of helmet-mounted display (HMD) symbology is that it allows the display of important tactical information for both air-to-air and air-to-ground applications. Moreover, it allows the pilot to take this information off-boresight thus giving an advantage in high off-boresight tactical maneuvers. In fact, previous research has shown several benefits of using HMDs, including the fact that they allow pilots to look further off-boresight and for longer periods of time than if they didn't have an HMD. [1,2,3]

However, given that, with HMDs, pilots will spend more time looking off-boresight, the need arises to not only give targeting information but also ownship status information (airspeed, heading, altitude, and attitude) so as to maximize the situation awareness (SA) of the pilot. Previous research has shown that in laboratory experiments as well as flight tests, pilots concur that ownship status information should be included off-boresight. [1,2,3,4,5,6,7]

There is, however, a question that arises when ownship status information is taken off-boresight. Namely, what is the best orientation, or frame of reference, for attitude symbology against the horizon (i.e., forward versus line-of-sight) in order to maximize interpretation and performance. To investigate this question two different tasks were tested (attitude maintenance and commanded attitude) facing the monitor (on-boresight) and turned ninety degrees so that the pilot had to look to the right to see the monitor (off-boresight). To explain the frame of reference manipulation, consider the case where one puts the standard head-up display (HUD) symbology on an HMD. If the pilot looks off-boresight, and the attitude symbology (i.e., bank and climb/dive angle) looks the same as if it were still on the HUD, this would be termed forward referenced. In this

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case, looking ninety degrees off-boresight the symbology would no longer be conformal with the horizon. However, if the attitude component became conformal with the horizon, this would be termed the line-of-sight frame of reference. The purpose of this study was to evaluate a number of candidate symbologies as well as the two frame of reference manipulations to see which gave the best ownship status information during the two different tasks.

2. METHOD

2.1 Participants

A total of 10 pilots volunteered to participate in the study with between 41 and 3000 hours of flight experience.

2.2 Symbol sets

There were five symbology sets compared in the present study. Each pilot participated in the experiment with only one of the five symbol sets. Three of the five symbol sets had both a forward as well as a line-of-sight version: standard HUD, Theta Ball, and the Arc-Segmented Attitude Reference / Wing Arc Vector (ASAR/WAV). The other two symbol sets were forward referenced only: the Visually Coupled Acquisition and Targeting System (VCATS), and the Non-Distributed Flight Reference (NDFR). Throughout the experiment, each symbol set displayed only airspeed, heading, altitude, and attitude (bank and climb/dive angle) information.

2.2.1 Standard HUD symbology

A representational version of MIL-STD-1787B [8] was used and can be seen in Figure 1. In this figure, and the figures to

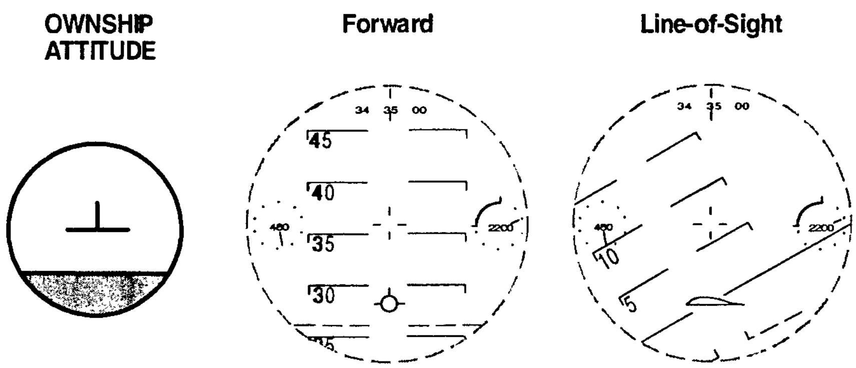

Figure 1. Standard HUD symbol set.

follow, an ownship attitude symbol is shown (approximately 28 degrees nose high) followed by the representative symbol set. Further, if the symbol set has a line-of-sight version it, too, will be shown. Note in Figure 1 several things about the line-of-sight version of the HUD. First, there is a wing reference to indicate that the symbology represents line-of-sight, and therefore conformal, information. Second, since the mechanization is conformal with the horizon, the pitch ladder now represents roll, and likewise the amount of pitch is read via the horizon line and the wing reference.

2.2.2 Theta Ball symbology

A second symbology called Theta Ball [9,10] was used and can be seen in Figure 2. Theta Ball was developed as a symbology that integrates a standard attitude/direction indicator (ADI) and standard HUD. Included within the ball are an enhanced horizon line as well as alphanumerical cardinal headings. There are also longitudinal lines that increment in 45 degree sections, and the ball rotates about all three axes thus representing roll, climb/dive, and heading. Further, the top half of the ball has solid lines while the bottom half is segmented. This symbology also has both a forward and line-of sight version as can be seen in Figure 2.

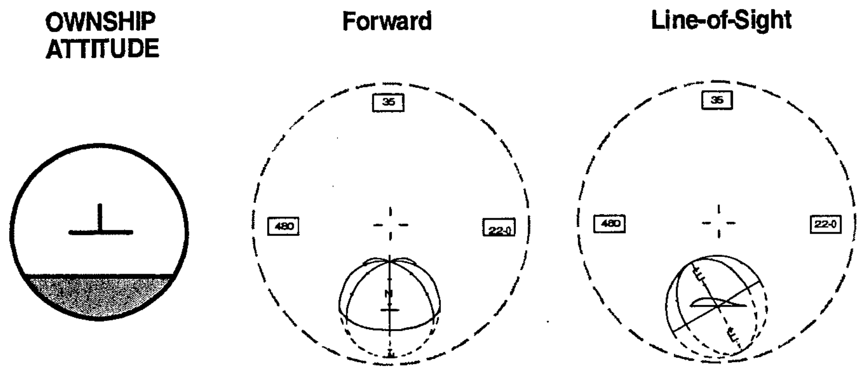

Figure 2. Theta Ball symbol set.

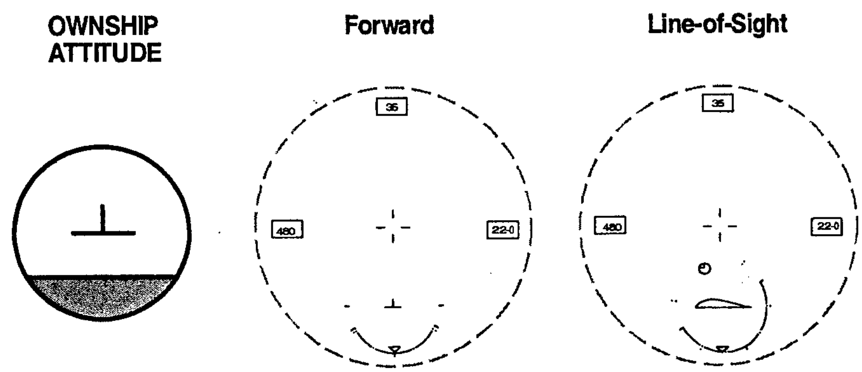

Figure 3. ASAR/WAV symbol set.

2.2.3 Arc-Segmented Attitude Reference / Wing Arc Vector (ASAR/WAV) symbology

A third symbology called ASAR/WAV [11] is shown in Figure 3. The ASAR, sometimes referred to as an "orange peel", was developed for the German Air Force and represents attitude by an arc surrounding a fixed climb/dive symbol. During straight and level flight the arc is a half circle, and as climb/dive increases (as in Figure 3) the arc area shrinks. Likewise, as climb/dive decreases the arc increases in area to form a complete circle at 90 degrees nose high. When performing a roll maneuver the arc will rotate about the fixed climb/dive symbol. This symbol set is the last one in the experiment that has a line-of-sight version as can be seen in Figure 3.

2.2.4 Non Distributed Flight Reference (NDFR) symbology

NDFR [3,12] was the fourth symbol set used and is shown in Figure 4. This is the first of the two symbol sets that did not have a line-of-sight version. Note that the reason for this is there is no room for the wing reference in the NDFR symbol set. NDFR was developed by the Air Force Research Lab as a flight reference that takes up less real estate than other contemporary symbol sets. The mechanization of NDFR is similar to ASAR/WAV in that both use the "orange peel" arc for attitude information. However, NDFR brings in airspeed, heading, and altitude around a flight path marker to give the pilot all of the ownship status information in a small well defined area. Previous research with NDFR has shown that pilots prefer this compressed information and often refer to it as a quick information stamp that allows them to help maintain their situation awareness. [3]

2.2.5 Visually-Coupled Acquisition and Targeting System (VCATS) symbology

The final symbol set used was VCATS and is shown in Figure 5. This symbol set was developed by the USAF and the Boeing Corporation as a high altitude ownship attitude reference. Attitude is mechanized by a single split horizon with a climb/dive angle reference. The horizon line will, during a roll maneuver, rotate about the fixed climb/dive symbol. In a climb, the line will move above the climb/dive symbol. In a dive, the line drops below the symbol and becomes segmented.

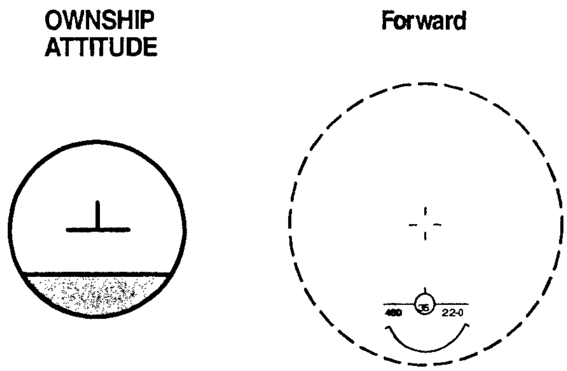

Figure 4. Non Distributed Flight Reference symbol set.

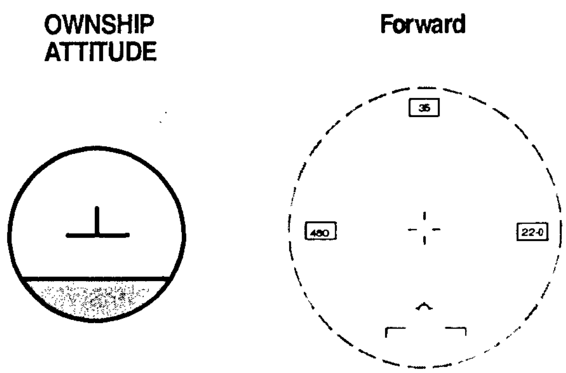

Figure 5. Visually-Coupled Acquisition and Targeting System symbol set.

2.3 Experimental tasks

The entire experiment consisted of four parts: free flight, criterion, attitude maintenance task, and commanded attitude task. Pilots were randomly assigned to one of the five candidate symbol sets upon arrival. They were briefed as to the purpose of the experiment, and given a verbal as well as pictorial overview of the symbol set they would be using. All stimuli were presented on a Silicon Graphics O2 with a 17-inch monitor (1024 x 768 resolution).

2.3.1 Free flight

The first part of the experiment allowed the pilots to familiarize themselves with their selected symbol set, for as long as they needed to feel they understood the mechanizations of the symbology. Throughout the experiment there was always a grid representing ground and a dark gray sky. Initially, during free flight, pilots faced the monitor. However, as part of each task would require them to fly "looking off-boresight", when they felt comfortable with the flight dynamics and the symbology, they were turned 90 degrees and allowed to free-fly looking off-boresight. It should be noted here that the experimenter then pressed a button that changed the dynamics of the simulation such that the outside view shown on the monitor looked as it would if flying while looking off-boresight. All pilots did this initially using the forward referenced version of the symbol set, but in the case where a pilot's symbology had a line-of-sight reference, they were allowed, once they felt comfortable with the forward referenced symbology, to fly with the line-of-sight referenced version of the symbology.

2.3.2 Criterion task

Once the pilot felt comfortable with the mechanization of the symbology, both on- and off-boresight, the criterion phase of the experiment began. In this phase the purpose was to get each pilot used to flying straight and level without any symbology with simulated turbulence. The rationale was to make sure each pilot was proficient with the flight dynamics to continue the experiment. The turbulence was designed so that it was replicable but not predictable. The disturbance function that simulated the turbulence was a gaussian random function that was run at 60 Hz. The function was scaled such that if no stick input was given, the root mean squared (RMS) error would be 8 (note that the unit is arbitrary as it is a function of the disturbance function) for both roll and climb/dive. Thus if one could perfectly predict and dampen the turbulence, a RMS error score of 0 would be obtained for both roll and climb/dive. Further, with no stick input the attitude deviations would be no more than +/- 60 degrees for roll and +/- 30 degrees for climb/dive. The pilot began each trial by pressing the trigger on the stick, which initiated the trial, beginning with 3 seconds of no turbulence, then 17 seconds of the simulated turbulence, and ending with 7 seconds of no turbulence. During the trial, pilots were instructed to maintain straight and level flight. They were further instructed that, once the turbulence ended, they were to make sure they were back at straight and level. After each trial, they were shown the RMS error values for both roll and climb/dive for the trial, and starting with the tenth trial they were shown a moving average of the last 10 trials' RMS error values for roll and climb/dive. Their task was to achieve an average RMS error value of 2.9 or below for roll, and 3.4 or below for climb/dive for ten trials. Once this was accomplished, the criterion phase of the experiment was completed. All ten pilots completed criterion, this required anywhere from 10 trials to 80 trials.

2.3.3 Attitude maintenance task

After reaching criterion, without the use of symbology, the attitude maintenance task began. This task was similar to the criterion phase of the experiment, but now the pilot's were given their candidate symbology to help them maintain straight and level flight. All pilots first ran 56 trials facing the monitor, after which they were turned 90 degrees and ran 56 more trials looking off-boresight. However, if a pilot's candidate symbology set had both forward and line-of-sight versions, they ran 56 forward and 56 line-of-sight trials. The forward versus line-of-sight manipulation was counterbalanced such that every other pilot ran the line-of-sight trials before running the forward referenced trials. As before, after each trial, RMS error for roll and climb/dive were given as well as a moving average RMS error of ten trials. Pilots were not told to reach a criterion but to do the best they could and to use the RMS error as a gauge as to their performance.

2.3.4 Commanded attitude task

The second part of the experiment was the commanded attitude task in which pilots had to interpret the symbology given to them and then fly to a new commanded attitude. Figure 6 shows a screen shot of the beginning of a trial using standard HUD. The first task of the pilot (the interpretation task) was to pick which of the eight command attitude cues corresponded to the attitude of the symbology (i.e., in this example 45 degrees banked left or number 4). The command attitude cues were, starting on the top row: nose high, nose low, roll right, and roll left; on the bottom row: inverted nose high, inverted nose low, inverted roll left, and inverted roll right. The pilots were told to select the correct command attitude cue via a bank of eight

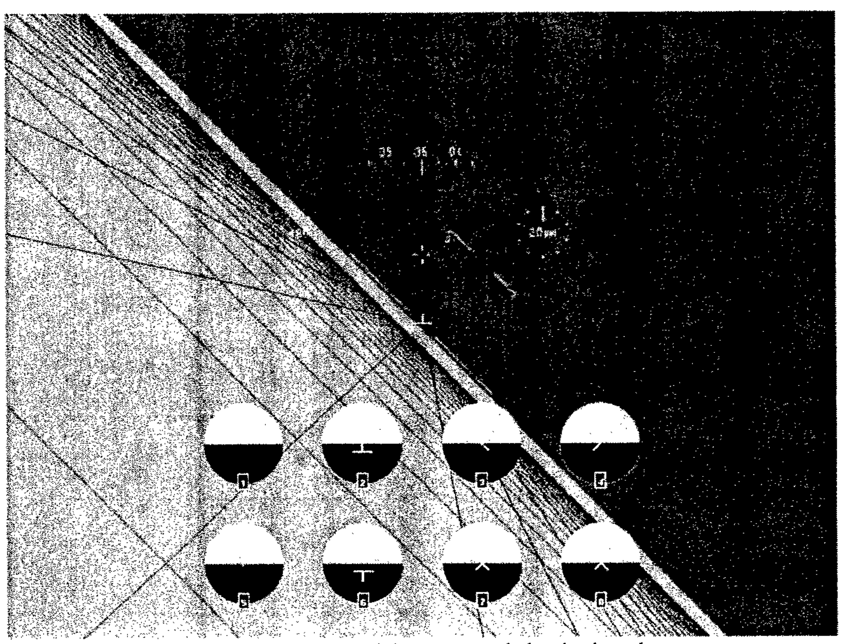

Figure 6. Part one of the commanded attitude task.

buttons as quickly as possible. If incorrect, the words "Incorrect Try Again" appeared and the pilot was allowed further selections until the correct answer was given.

Once the correct answer was given, the display would "go live" (commanded attitude task) and the pilot was given a command attitude cue to fly to a new attitude. This cue was one of the previously displayed choices for the first part of the task minus the attitude that the pilot had just correctly identified. To end the trial the pilot had to maintain the specified new attitude for approximately two seconds. Pilots were told before starting the second part of the experiment that the nose high and nose low attitudes were 28 degrees and the rolls were 45 degrees. As in the first part of the experiment, 56 trials were completed facing the monitor, followed by either 56 or 128 trials looking off-boresight (56 forward and 56 line-of-sight) depending upon the pilot's candidate symbology. It should be noted that this phase of the experiment was designed to be more of an operational task than a typical recovery task and thus further assess the usefulness of the symbol sets being tested.

3. RESULTS

3.1 Analysis of the attitude maintenance task

The analysis of the attitude maintenance task was performed as a between-subjects design with two pilots per symbol set. For both the forward and off-boresight conditions, as well as the frame of reference conditions (forward versus line-of-sight) the RMS error for roll and climb/dive were analyzed. To help normalize the data, all data were log transformed before analysis.

3.1.1 Attitude maintenance task - Forward condition

An Analysis of Variance (ANOVA) was performed on the log RMS error data and revealed a significant effect of symbol set for both climb/dive error $F(4,280) = 16.88$, $p < .0001$, and roll $F(4,280) = 28.28$, $p < .0001$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed significant differences for climb/dive error between NDFR and the other four symbol sets (i.e., ASAR/WAV, VCATS, HUD, and Theta were not significantly different from each other) as can be seen in Figure 7. Post hoc analysis on the log RMS roll error revealed no significant difference between Theta and VCATS, or between HUD and ASAR/WAV; however both of these groupings were significantly different from each other and from NDFR. These results are shown in Figure 8.

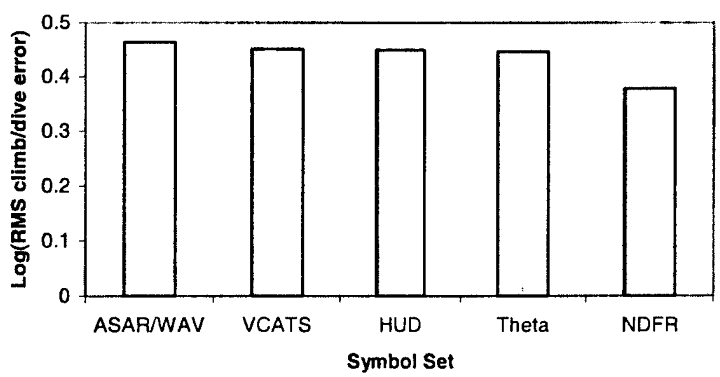

Figure 7. Log RMS error for climb/dive.

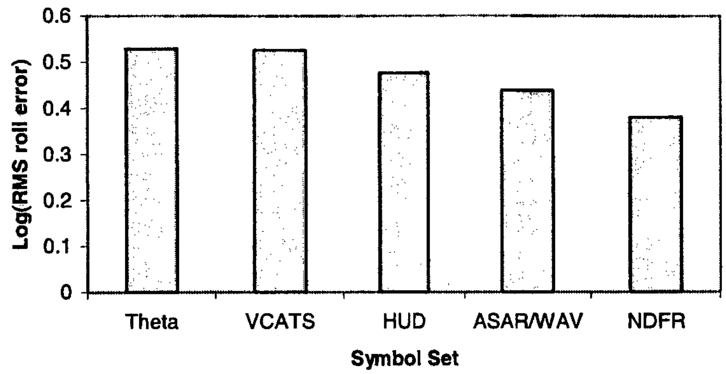

Figure 8. Log RMS error for roll.

3.1.2 Attitude maintenance task – Off-boresight condition

In order to evaluate the effect of the two frame of reference manipulations (i.e., forward versus line-of-sight), an ANOVA was performed on the three symbol sets that had both references (ASAR/WAV, HUD, and Theta). The analysis revealed a significant effect of frame of reference for log RMS climb/dive error $F(1,666) = 31.56$, $p < .0001$ with the average forward referenced errors lower than the average line-of-sight errors. Analysis of the log RMS roll error was not significant $F(1,666) = 1.82$, $p > .05$. Since these results show that forward referenced symbology was better than, or equal to, line-of-sight referenced symbology, a second ANOVA was performed on the error data for only the forward referenced conditions. This analysis revealed a significant effect of symbol set for both climb/dive error $F(4,280) = 15.02$, $p < .0001$, and roll error $F(4,280) = 11.17$, $p < .0001$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed no significant differences for climb/dive error between the following groups: (VCATS and ASAR/WAV), (ASAR/WAV, NDFR, and Theta) and (NDFR, Theta, and HUD), and can be seen in Figure 9. Post hoc analysis of the roll error revealed significant differences between VCATS and the other four symbol sets (i.e., ASAR/WAV, HUD, Theta, and NDFR). These results are shown in Figure 10.

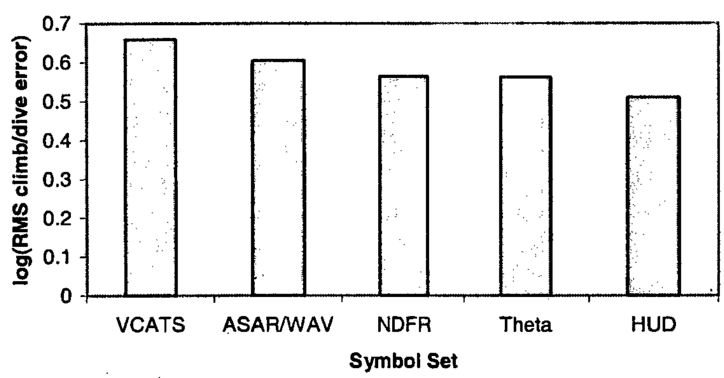

Figure 9. Log RMS error for climb/dive forward referenced only.

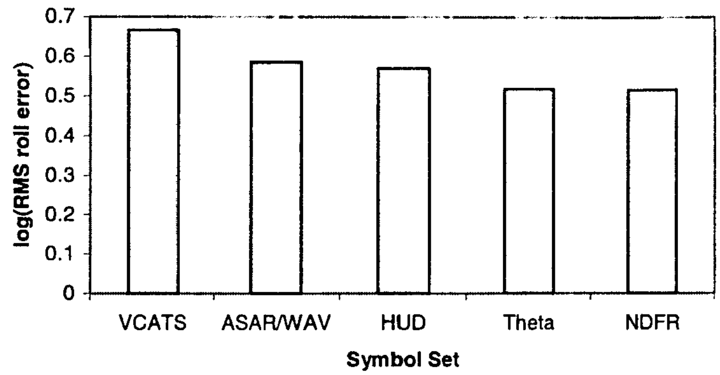

Figure 10. Log RMS error for roll forward referenced only.

3.2 Analysis of the commanded attitude task

The analysis of the commanded attitude tasks was performed as a between-subjects design with two pilots per symbol set. For both the forward and off-boresight conditions, as well as the frame of reference conditions (forward versus line-of-sight), the reaction times (RTs) for the interpretation task were analyzed, and for the commanded attitude task the initial stick input RT and total RT (i.e., total time to fly to new commanded attitude) were analyzed. To help normalize the data all data was log transformed before analysis as was done in the attitude maintenance task.

3.2.1 Commanded attitude tasks – Forward condition

An ANOVA was performed on the interpretation task log RT data and revealed a significant effect of symbol set $F(4,480) = 4.21$, $p < .0023$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed significant differences only for Theta and NDFR. There were no significant differences between Theta, VCATS, ASAR/WAV and HUD, or between VCATS, ASAR/WAV, HUD, and NDFR. These results are shown below in Figure 11. For the commanded attitude task, an ANOVA was performed on the initial stick input log RT data and revealed a significant effect of symbol set

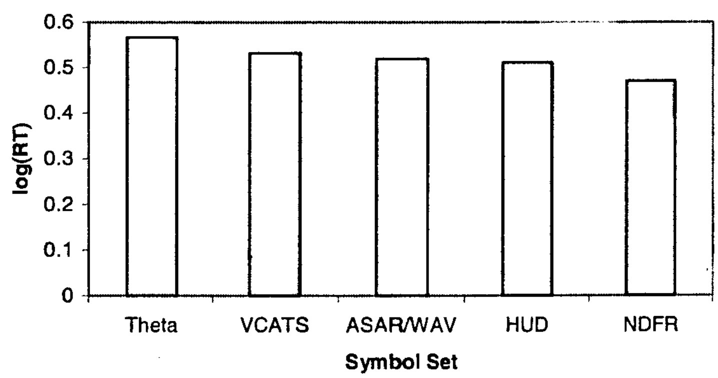

Figure 11. Log (RT) for interpretation task.

$F(4,80) = 24.39$, $p < .0001$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed no significant differences between Theta and HUD, or between ASAR and VCATS. However both of these groupings were significantly different from each other, and from NDFR, and these results can be seen in Figure 12. Finally, an ANOVA was performed on the total log RT data and revealed a significant effect of symbol set $F(4,278) = 10.90$, $p < .0001$. Post hoc

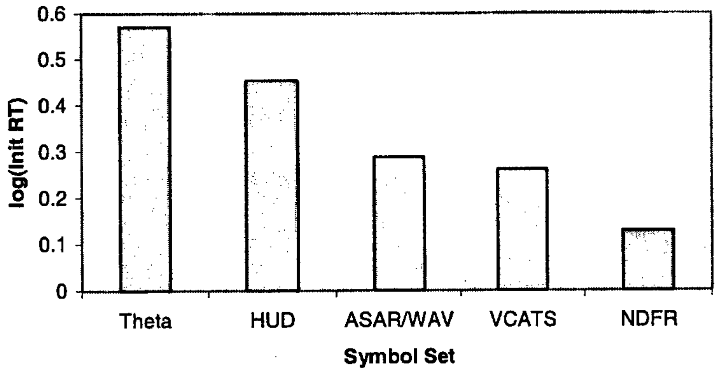

Figure 12. Log (Initial stick input RT) for commanded attitude task.

analysis on these data using Tukey's HSD test at the .05 alpha level revealed no significant differences between HUD, VCATS, and ASAR/WAV, or between VCATS, ASAR/WAV, and NDFR, however Theta was significantly different from all of the symbol sets as can be seen in Figure 13.

3.2.2 Commanded attitude tasks – Off-boresight condition

As in the attitude maintenance analysis, to evaluate the effect of the two frame of reference manipulations, an ANOVA was performed on the three symbol sets that had both references (ASAR/WAV, HUD, and Theta). The analysis was first conducted on the interpretation log RT data revealed no significant effect of frame of reference for RT $F(1,590) = 1.60, p >$

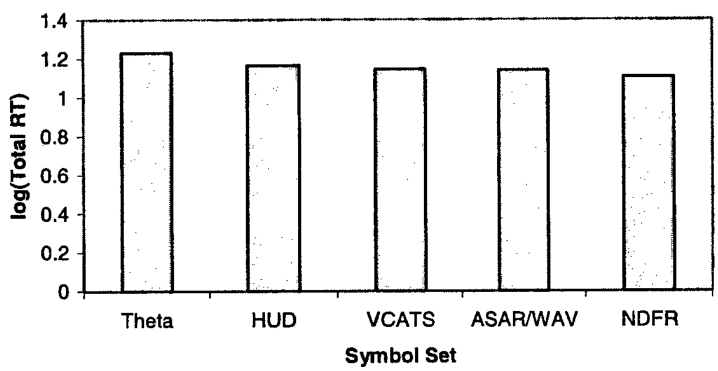

Figure 13. Log (Total RT) for commanded attitude task.

.05. Since these results show that forward referenced symbology was equal to line-of-sight referenced symbology, a second ANOVA was performed on the interpretation task log RT data for only the forward referenced conditions. This analysis revealed a significant effect of symbol set $F(4,499) = 15.95, p < .0001$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed no significant differences between VCATS, HUD, Theta, and ASAR/WAV, but all four were significantly different from NDFR as can be seen in Figure 14.

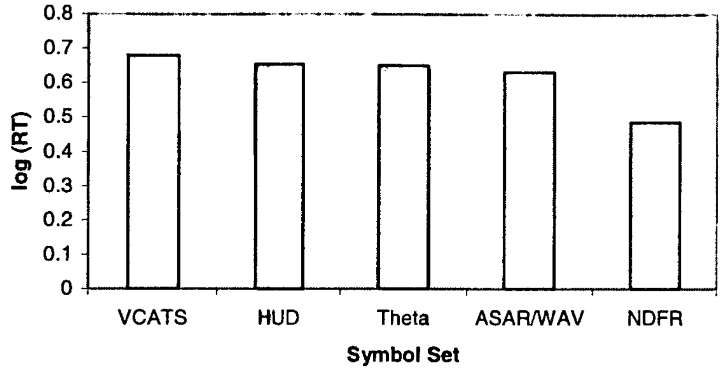

Figure 14. Log (RT) for interpretation task forward referenced only.

For the commanded attitude task, an ANOVA was performed on the three symbol sets that had both references (ASAR/WAV, HUD, and Theta) to check the frame of reference manipulation. The analysis was conducted on both the initial stick input log RT data as well as the log Total RT data. The analysis on the initial stick data revealed a significant effect of frame of reference $F(1,379) = 7.19$, $p < .001$ with forward referenced having lower RTs than line-of-sight referenced symbology. The total RT data however revealed no significant difference for frame of reference $F(1,662) = 2.4$, $p > .05$. As before, since the analysis revealed that forward referenced was either better than, or the same as, line-of-sight referenced symbology, another analysis was conducted on the forward referenced only conditions. This analysis revealed a significant effect of symbol set for initial stick input RT $F(4,335) = 4.77$, $p < .0009$, as well as total RT $F(4,554) = 12.51$, $p < .0001$. Post hoc analysis on these data using Tukey's HSD test at the .05 alpha level revealed no significant differences for initial stick input RT between, HUD, ASAR/WAV, NDFR, and Theta, or between ASAR/WAV, NDFR, Theta, and VCATS, and can be seen in Figure 15. Post hoc analysis the total RT data revealed significant differences between NDFR and the other four symbol sets (i.e., ASAR/WAV, HUD, Theta, and VCATS). These results are shown in Figure 16.

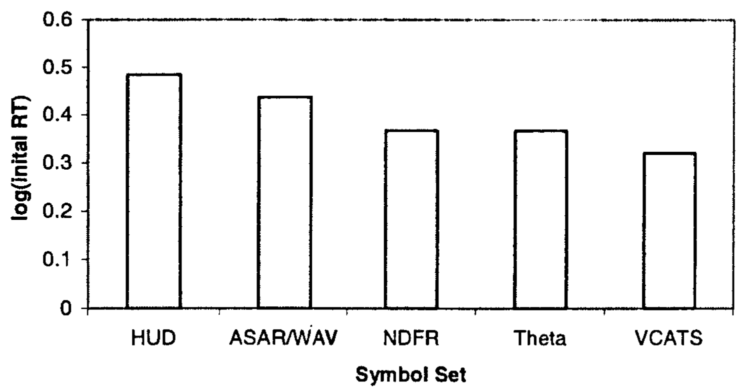

Figure 15. Log (initial stick input RT) forward referenced only.

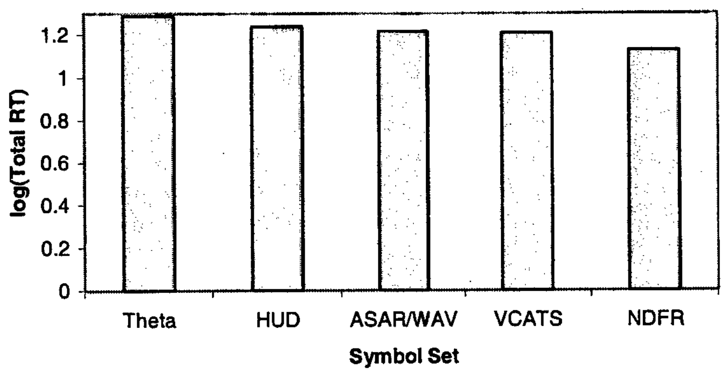

Figure 16. Log (total RT) forward referenced only.

3. DISCUSSION

The purpose of this experiment was twofold. First, we wished to investigate the effect of two different frames of reference (forward versus line-of-sight) for attitude symbology to be used both on- and off-boresight. Secondly, we wanted to understand what is the best symbol set to use to present ownship status information for two different aircraft control tasks (attitude maintenance and commanded attitude). In the first part of the experiment, pilots had to maintain straight and level flight while flying looking either on or off-boresight. The results indicate that when flying on-boresight, the NDFR symbology allows better control, as shown by lower RMS errors for roll and climb/dive. When this task was performed while looking off-boresight, the pilots performed better with forward as opposed to line-of-sight symbology. Further analysis revealed that, for the forward referenced versions of the symbol sets, there is no clear "winner". However, this task was very difficult and it was pointed out by several of the pilots that, given the same situation in actual flight, they would immediately come back inside the cockpit and fly on-boresight.

In the second half of the experiment, pilots first had to interpret the attitude of the displayed symbology and then they were commanded to fly to a new attitude. Analysis indicates that, when performing the task on-boresight, reaction times for choosing the correct attitude were fastest using NDFR; however NDFR was not significantly different from any of the other symbol sets except Theta. For the recovery task, initial stick input was significantly faster for NDFR, yet total RT is the same for all symbol sets except for Theta (the slowest). Further analysis reveals that, when the task was performed looking off-boresight, performance was better with forward referenced symbology, as it was in the first part of the experiment, for both the interpretation task and the commanded attitude task. Moreover, results indicated that for the interpretation task performance was best with NDFR. Further, for the commanded attitude task, there was no clear winner for best performance for initial stick input, however NDFR outperformed the other symbologies for total RT.

In summary, we find that, when symbology is to be taken off-boresight, it is best to leave it forward referenced. This result alleviates the concern over how to mechanize a line-of-sight symbology. In other words: when, as pilot's head turns, would it change from forward to line-of-sight referenced? Performance results indicate that pilots perform the same, if not better, during an off-boresight task when the symbology is forward referenced. Further, we also have shown a benefit of the NDFR symbology as a simple, small footprint, ownship status symbology that, in general, performs as well as, or in many cases, outperforms other symbol sets.

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REFERENCES

1. R.K. Osgood, E.E. Geiselman, and C. Calhoun, "An evaluation of an off-boresight helmet-mounted display for a simulated flying task," *AGARD conference proceedings 517, Helmet-Mounted Display and Night Vision Goggles*, pp. 14.1-14.7, 1991.

2. E.E. Geiselman, and R.K. Osgood, "Utility of off-boresight helmet-mounted symbology during a high angle airborne target acquisition task," In Lewandowski, R.J., Stevens, W., and Haworth, L.A. (Eds.), *Proceedings of the International Society for Optical Engineers (SPIE): Helmet- and Head-mounted Displays and Symbology Design Requirements*, 2218, pp. 328-338, 1994.

3. E.E. Geiselman, P.R. Havig, and M.T. Brewer, "A non distributed flight reference symbology for helmet-mounted display use during off-boresight viewing: development and evaluation," In Lewandowski, R.J., Haworth, L.A., and Girolamo, H.J. (Eds.), *Proceedings of the International Society for Optical Engineers (SPIE): Helmet- and Head-mounted Displays V*, 4021, pp. 272-283, 2000.

4. General Dynamics Corporation, "Night attack program pilot-vehicle interface study," *CCP 10113 Final Report*, 1992.

5. S.C. Boehmer, "X-31 helmet mounted visual & audio display (HMVAD) system," In Lewandowski, R.J., Stevens, W., and Haworth, L.A. (Eds.), *Proceedings of the International Society for Optical Engineers (SPIE): Helmet- and Head-mounted Displays and Symbology Design Requirements*, 2218, pp. 150-160, 1994.

6. R.K. Osgood, and D.R. Chapman, "JSF integrated helmet audio-visual technology demonstration results," In Lewandowski, R.J., Haworth, L.A., and Girolamo, H.J. (Eds.), *Proceedings of the International Society for Optical Engineers (SPIE): Helmet- and Head-mounted Displays*, 3058, pp. 332-335, 1997.

7. S.D. Fechtig, G.S. Boucek, and E.E. Geiselman, "Preliminary results of the effective information fusion for helmet mounted display technologies program," *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment*, Naval Air Warfare Center – Aircraft Division. Patuxent River, MD, pp 51-68, 1998.

8. MIL-STD-1787B (USAF), "Military standard practice: Aircraft display symbology," 20 October, 1995.

9. E.E. Geiselman, R.K. Osgood, and D.W. Biers, "A comparison of three aircraft attitude display symbology structures," AL/CF-TR-1993-0134, Interim Report December 1990 – December 1991 AFMC, Wright-Patterson AFB, Ohio.

10. D.P. Meador, E.E. Geiselman, and R.K. Osgood, "Helmet display symbology for the JAST/IHAVS flight demonstration," In Lewandowski, R.J., Haworth, L.A., Stephens, W., and Girolamo, H.J. (Eds.), *Proceedings of the International Society for Optical Engineers (SPIE): Helmet- and Head-mounted Displays*, 2735, pp. 39-49, 1996.

11. G. Fischer, and W. Fuchs, "Symbology for head-up and head-down applications for highly agile fighter aircraft – to improve spatial awareness, trajectory control and unusual attitude recovery," *AGARD Symposium on Combat Automation of Airborne Weapon Systems Man/Machine Interface: Trends and Technologies*, AGARD-CP-520, Edinburgh, 19-22 October, 1992.

12. E.E. Geiselman, "Development of a non-distributed flight reference symbology for helmet-mounted display use during off-boresight viewing," *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment*, Naval Air Warfare Center – Aircraft Division. Patuxent River, MD, pp 118-127, 1999.